NEUTRINOS

AT THE

MAIN INJECTOR

Project Execution Plan

February 1999

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Submitted by:

Ronald J. Lutha, DOE/NuMI Project Manager
DOE Fermi Group

2/8/99
Date

Robert C. Wunderlich, Acting Group Manager
DOE Fermi Group

2/8/99
Date

John P. Kenndy, Acting Manager
DOE Chicago Operations Office

2/10/99
Date

Philip H. Debenham, DOE/NuMI Program Manager
Division of High Energy Physics

2-11-99
Date

John R. O'Fallon, Director
Division of High Energy Physics

2/11/99
Date

S. Peter Rosen, Associate Director
Office of High Energy and Nuclear Physics

2/11/99
Date

Approved by:

Martha A. Krebs, Director
Office of Science

2/17/99
Date

NEUTRINOS AT THE MAIN INJECTOR
PROJECT EXECUTION PLAN

TABLE OF CONTENTS

1. Introduction

1.1 Purpose and Context of This Document

This Project Execution Plan (PEP) for the Neutrinos at the Main Injector (NuMI) project describes the mission need and justification of the project, its objectives and scope, the Department of Energy (DOE) management structure, the resource plan, and the environmental, safety, and health requirements. In addition, it establishes the technical, cost, and schedule baselines against which project execution will be measured by the DOE. It also identifies which DOE management level is authorized to approve changes to each baseline.

The project is being executed by Universities Research Association, which operates Fermi National Accelerator Laboratory (Fermilab) under contract for the DOE. The NuMI Project Management Plan (PMP), a companion document to this PEP, describes the organization and systems that the contractor will employ to manage execution of the project and report to the DOE. It also establishes the more detailed baselines against which the contractor will measure project execution.

1.2 Approval and Revision

The PEP is approved by the Director of DOE's Office of Science (SC-1) as an element of Critical Decision 2, Approval of Baseline. Revisions to the PEP that are required to incorporate baseline change actions are considered to be approved by virtue of the corresponding baseline change. Approval of revisions to the PEP that are not connected with baseline changes has been delegated to the Director of DOE's Division of High Energy Physics (DHEP). The DOE NuMI Project Manager is authorized to approve non-substantive changes to the PEP and to update the document with appropriate factual material that reflects project development (such as actual dates that project milestones are accomplished), without higher level approval.

The PMP is approved by both the DOE NuMI Project Manager and the Director of the DHEP.

2. Mission Need and Objectives

2.1 Programmatic Mission

The mission of the DHEP is to support the Director of SC in providing effective planning, funding, and management of the DOE High Energy Physics (HEP) program. In doing so, the Division is a principal focus in carrying out the Department's role as the designated Executive Agent for the United States HEP program. The mission of the HEP program is to understand the fundamental nature of matter and energy and the forces, which govern their behavior.

The mission of Fermilab is to advance the understanding of the fundamental nature of matter and energy by providing leadership and resources for qualified researchers to conduct basic research at the frontiers of HEP and related disciplines.

2.2 Project Support of Program Mission

The NuMI Project at Fermilab will provide the U.S. HEP program with a world-class facility for studying the physics of neutrino systems in general and, more specifically, addressing the fundamental question of the mass of neutrinos.

A full description of how the NuMI Project furthers the mission of Fermilab and the DOE DHEP program is set forth in Attachment 9.1. The Director of the Office of Energy Research (previous organization to the Office of Science) approved this document, which constitutes Critical Decision 1 in accordance with DOE Order 430.1, on March 17, 1997.

3. Project Description

The NuMI project will be constructed at Fermilab in Batavia, Illinois, and at the Soudan Underground Laboratory (SUL) in Soudan, Minnesota. Fermilab is a contractor-operated DOE laboratory, and SUL is owned by the State of Minnesota and operated by the University of Minnesota.

The purpose of the NuMI project is to build a facility for studying the physics of neutrinos. The proton beam of the Fermilab Main Injector will be used to produce a very intense neutrino source. The project includes the design and construction of a beam line and experimental facilities at the Fermilab site, two multi-purpose detectors for the Main Injector Neutrino Oscillation Search (MINOS) experiment (a near detector at Fermilab and a far detector at the SUL), and modifications to the SUL to accommodate the far MINOS detector.

The NuMI beam line will produce an intense beam of neutrinos to enable a new generation of experiments whose primary scientific goal is to definitively detect and study neutrino oscillations. The beam will be of sufficient intensity and energy so that experiments capable of identifying muon neutrino to tau neutrino oscillations are feasible. A beam of protons from Fermilab's Main Injector will be used to produce the neutrino beam by directing it onto a production target. The interaction of the proton beam with the target will produce mesons, which will decay into muons and neutrinos during their flight through a decay tunnel. An absorber downstream of the decay region will remove the remaining protons and mesons from the beam. The muons will be absorbed by the intervening earth shield while the neutrinos continue through it to the near experimental hall and beyond to the far detector in the SUL.

The experimental halls will contain massive detectors specially designed to detect the relatively few neutrinos that will interact in them. A near detector located on the Fermilab site will provide a measurement of the neutrino rate and energy spectrum near the point where they are produced. A far detector in the SUL will measure these same quantities 730 km from the near detector. Evidence for neutrino oscillations will be sought by comparing the neutrino interaction rates and energy spectra in the near and far detectors.

Attachment 9.2 contains an aerial view of the NuMI beam line and a map of the neutrino beam trajectory.

3.1 Scientific Objectives

The probability that a neutrino will oscillate from one type to another is given by the expression

$$P = \sin^2(2\theta)\,\sin^2(1.27\Delta m^2 L/E).$$

Here θ is the mixing angle between the two neutrino types, Δm^2 is the difference between the squares of their masses (eV^2), L is the distance traveled (km) and E is the neutrino energy (GeV). For NuMI, L is firmly established by locating the MINOS far detector at Soudan and E is constrained by the NuMI primary beam energy. The parameters $\sin^2(2\theta)$ and Δm^2 must be determined by experiment and the range of possible values for them is referred to as the parameter space for neutrino oscillations. The following sections describe the scientific objectives in exploring this parameter space.

3.1.1 Detection of Neutrino Oscillations

The primary scientific objective of the MINOS experiment is to definitively detect neutrino oscillations or, if neutrino oscillations do not occur within the region of parameter space accessible to the MINOS experiment, to place stringent new constraints upon where oscillations might occur. The specific region of parameter space to be explored and the methods of detecting neutrino oscillations are fully discussed in The MINOS Detectors Technical Design Report (October 1998).

3.1.2 Identification of Oscillation Channel(s)

There are three known types of neutrinos: ν_e, ν_μ, and ν_τ. A fourth, non-interacting type, known as the "sterile neutrino", is suggested by some theories. The NuMI neutrino beam is composed almost entirely of ν_μ. Hence the goal of the MINOS experiment is to find a clear signal for $\nu_\mu \rightarrow \nu_x$, where x represents one of the other neutrino types. The beam will be of sufficient energy to produce τ leptons, which would identify $\nu_\mu \rightarrow \nu_\tau$ oscillations. If oscillations occur, the MINOS detector will identify the non-μ neutrino flavor(s) and thus the oscillation channel(s).

3.1.3 Measurement of Neutrino Oscillation Parameters

If neutrino oscillations are detected, the MINOS experiment will measure the neutrino oscillation parameters Δm^2 and $\sin^2(2\theta)$ for each oscillation channel observed. The beamline will be optimized to search the region of parameter space that the data from recent experiments indicates is most likely to contain the actual parameters for ν_μ oscillations.

3.2 Technical Goals

The critical technical goals of the NuMI project are listed in Table 3.1. The commissioning goals are the parameter values that must be achieved for approval to start operations (Critical Decision 4). The operational goals, which are needed for the project to accomplish its scientific objectives, are expected to be reached after several years of operation.

Table 3.1
NEUTRINOS AT THE MAIN INJECTOR
Technical Goals

Parameter	Measurement	Commissioning Goal	Operational Goal
Proton intensity in target hall	Toroid beam monitor	1×10^{13}/spill	4×10^{13}/spill 3.6×10^{20}/year
Neutrino beam energy	Near detector event energy	Medium energy, 4-8 GeV	Low energy, 2-4 GeV Medium energy, 4-8 GeV High energy, 8-16 GeV
Near detector neutrino flux	Charged current event rate in 1.5 ton fiducial region	0.045 ± 0.014 events/spill	0.18 ± 0.05 events/spill
Far detector neutrino flux*	Charged current event rate	$(1.9 \pm 0.6) \times 10^{-5}$ events/kton/spill	$(7.6 \pm 2.3) \times 10^{-5}$ events/kton/spill
Muon momentum resolution+	Curvature vs. range in magnetic overlap region	20%	14%
Hadron energy resolution+	Test beam	None	$\Delta E/E = 70\%/E^{1/2} + 8\%$
Detection efficiency for charged current events+	Event length distribution	80 % with <10% neutral current contamination	90% with <4% neutral current contamination

*Assuming 50% reduction from neutrino oscillations
+Applies to both near and far detectors

3.3 Project Scope

A neutrino beamline will be constructed on the Fermilab site. Beamline components will be built for NuMI or recycled from existing beamlines at Fermilab, installed and tested prior to operation. They will produce a neutrino beam aligned with both the near and far experimental halls. The beam will be of sufficient intensity to conduct the long baseline neutrino research in the parameter space discussed in the preceding sections. The beamline design is more fully described in The NuMI Facility Technical Design Report (October 1998).

Civil construction for the NuMI Project at Fermilab will include the underground construction of tunnels and halls to accommodate the beamline components discussed above, an experimental hall which can accommodate the MINOS near detector, two shafts for access to the surface and a service building associated with each shaft. All underground construction will include sufficient radiation shielding to ensure compliance with applicable state and federal regulations when the NuMI beamline is operational. The civil construction is more fully described in The NuMI Facility Technical Design Report (October 1998).

Two detectors will be built, installed and tested for the MINOS experiment. The near detector will be installed in the experimental hall at Fermilab as a single module. Its neutrino detection capabilities will be similar to those of the far detector. The far detector will be installed as two supermodules. The detector design is more fully described in The MINOS Detectors Technical Design Report (October 1998).

An experimental hall will be constructed and outfitted at the Soudan Underground Laboratory. This hall will be capable of accommodating a MINOS detector comprised of either (a) three supermodules or (b) two supermodules and an emulsion detector.

4. DOE Organization and Responsibilities

The organization for the NuMI project is shown in Figure 4.1. Each of the major organizational elements is discussed below.

4.1 Division of High Energy Physics

Within the Office of Science, the Office of High Energy and Nuclear Physics has overall DOE responsibility for the development of high energy and nuclear physics. The Division of High Energy Physics (DHEP) is the lead organization for the NuMI project and will provide assistance, guidance and technical overview, overall program policy, planning, program development (including establishment of broad priorities) and budget preparation/defense (with support from the field organization). The prime headquarters point of contact for the project will be the NuMI Program Manager, a DHEP employee who is appointed by the Director of the DHEP.

- direct the periodic updating of the Project Execution Plan and the Project Management Plan.

- coordinate updates of the Construction Project Data Sheets (Schedule 44) for each budget cycle.

- participate in and provide support for the program peer reviews, reviews by oversight committees and validation of the project.

- submit quarterly reports and such other reports on the status of the project for DOE management as required in this Project Execution Plan and applicable DOE requirements.

- ensure compliance by the NuMI project with appropriate DOE requirements, e.g., ES&H and contracting regulations.

- issue construction project directives and any modifications thereto.

5. Resource Plan

The planned DOE funding for the NuMI project is shown in Table 5.1.

Table 5.1 Planned DOE Funding for the NuMI Project ($ in thousands)

	Prior Years	FY 1998	FY 1999	FY 2000	FY 2001	FY 2002	FY 2003	Total
Line Item Funds (TEC)	0	5,500	14,300	22,000	23,000	11,400	0	76,200
Other Project Costs	1,080	2,530	3,000	13,500	23,000	15,040	1,750	59,900
Total Project Costs	**1,080**	**8,030**	**17,300**	**35,500**	**46,000**	**26,440**	**1,750**	**136,100**

In addition to the DOE funding, the University of Minnesota has agreed to contribute $3.8 million towards modification of the Soudan Underground Laboratory to accommodate the far MINOS detector. An in-kind contribution of equipment for the MINOS detectors, valued at $6 million, is also expected from several institutions in the United Kingdom.

Fermilab project staffing requirements are 27 full-time employees in FY 1998, increasing to about 62 employees in FY 2001. In addition, the MINOS collaboration includes approximately 165 people at 22 institutions. The full-time equivalent DOE manpower assigned to this project is one person at FRMI, and approximately one person in DHEP, not including support services provided as necessary by CH.

6. Project Monitoring and Reporting

The DOE Project Manager will provide quarterly reports on the NuMI project to the DHEP. Real time monitoring of the NuMI project will occur through established mechanisms among project participants. Reviews of the project status will be conducted by the DHEP approximately semi-annually. Fermilab will provide formal project monthly reports to the DOE Project Manager. The requirements of the monthly reports will be included in the PMP.

7. Environment, Safety and Health

7.1 National Environmental Policy Act (NEPA)

The effects of the NuMI project on the environment, both in Illinois and Minnesota, are assessed in the NuMI Environmental Assessment (EA). This document also describes the means through which any potential adverse effects on the environment will be avoided, minimized, or mitigated in accordance with applicable regulations. The EA has served as the basis for determining that the NuMI Project did not require an Environmental Impact Statement. A Finding of No Significant Impact (FONSI), Attachment 9.3, for the NuMI project was issued on January 16, 1998.

7.2 Preliminary Safety Analysis Document

The NuMI Preliminary Safety Assessment Document addresses the safety and health considerations in the design, construction and operation of the NuMI beamline and associated experiments. This document will form the basis for the NuMI Safety Assessment Document.

8. Project Baselines and Control Levels

The project baselines and control levels are defined in a hierarchical manner that provides change control authority at the appropriate management level. The highest level of baseline change control authority is defined as Level 0. Changes at Level 0 are approved by the Director of the DOE Office of Science. Changes below Level 0 are approved as follows: Level 1- Director of the DOE Division of High Energy Physics; Level 2 - DOE NuMI Project Manager; and Level 3- Fermilab NuMI Project Manager.

The technical, cost, and schedule baselines and the associated control levels down to Level 2 are given in Table 8.1. The project technical baseline is defined by Section 3 of this document. The cost baseline is given in Table 8.2. The baseline schedule is shown as Attachment 7.4, and controlled milestones are given in Table 8.3 and defined in Attachment 7.5.

The change control levels and procedures at Level 3 and below are addressed in the Project Management Plan.

Table 8.1

NEUTRINOS AT THE MAIN INJECTOR
Technical, Cost and Schedule Baseline Control Levels++

	Director, Office of Science (Level 0)	Director, Office of High Energy Physics (Level 1)	DOE Project Manager (Level 2)
Technical	Construction of a world-class facility for studying the physics of neutrino systems	Scientific and technical objectives, commissioning goals, and design parameters as identified in the Project Execution Plan (Sections 3.1 and 3.2)	Project scope as identified in the Project Execution Plan (Section 3.3)
Cost	Any change to TEC or TPC (see Table 8.2)	Any change of greater than $5M at change control level 1 (see Table 8.2)	Any change of greater than $2M at change control level 2 (see Table 8.2)
Schedule	Any change to level 0 milestones (see Table 8.3)	Any change to level 1 milestones (see Table 8.3)	Any change to level 2 milestones (see Table 8.3)

++ Changes must be approved at all applicable lower levels before being forwarded to the next higher level for consideration.

Table 8.2

NEUTRINOS at the MAIN INJECTOR

Change Control Level and Project Cost by WBS Element ($ in Millions)

CHANGE CONTROL LEVEL	WBS ELEMENT	ITEM	COST
0	1.0	TOTAL ESTIMATED COST (TEC)	76.2
2	1.1	Technical Components	15.3
2	1.2	Facility	45.3
2	1.3	Project Management	2.8
2		Contingency	12.8
1	2.0	U.S. DETECTOR CONTRIBUTION*	44.6
2		Base Cost	33.5
2		Contingency	11.1
1	3.0	PROJECT SUPPORT†	15.3
0		TOTAL PROJECT COST (TPC)	136.1

* Does not include United Kingdom contribution of $6.0 million; includes detector installation funds.

† Does not include Minnesota State contribution of $3.8 million.

Table 8.3
NEUTRINOS AT THE MAIN INJECTOR
Controlled Milestones

Level 0 Milestones

Milestone No.	Description	Baseline Date	Actual Date
L-0-1	CD-1: Approve mission need	03-97	03-17-97
L-0-2	CD-2: Approve baselines	02-99	
L-0-3	CD-4: Start operations	09-03	

Level 1 Milestones

Milestone No.	Description	Baseline Date	Actual Date
L-1-1	CD-3a: Start limited construction	02-99	
L-1-2	CD-3b: Continue construction	04-99	
L-1-3	Far detector prototype erected	01-00	
L-1-4	Far detector excavation complete	10-00	
L-1-5	Target hall excavation complete	05-01	
L-1-6	Inner and outer conductors for first production horn assembled	11-01	
L-1-7	First far-detector super module complete and tested	07-02	
L-1-8	Far detector complete and tested	06-03	

Level 2 Milestones

Milestone No.	Description	Baseline Date	Actual Date
L-2-1	MINOS steel purchase subcontract awarded	04-99	
L-2-2	Top of Soudan #8 mineshaft located with GPS	06-99	
L-2-3	NTP issued for Fermilab underground subcontract	11-99	
L-2-4	High current pulse into prototype horn	03-00	
L-2-5	Fermilab underground construction 50% complete	08-00	
L-2-6	CalTech factory commissioned	09-00	
L-2-7	Near detector excavation complete	01-01	
L-2-8	Magnets for MI stub refurbished	04-01	
L-2-9	Outfitting of far detector enclosure complete	04-01	
L-2-10	Cosmic rays observed in far detector	09-01	
L-2-11	Beneficial occupancy of service buildings at Fermilab	12-01	
L-2-12	Lambertson and C-magnets assembled and tested	04-02	
L-2-13	First horn installed	12-02	
L-2-14	Near detector complete and tested	02-03	